Modifications of single-particle properties in nuclear matter induced by three-body forces

V. Somà[1] and P. Bożek[2,1]

[1]Institute of Nuclear Physics PAN, Kraków, Poland
[2]Institute of Physics, Rzeszów University, Rzeszów, Poland

November 25, 2008

Abstract

Within the self-consistent Green's functions formalism, we study the effects of three-body forces on the in-medium spectral function, self-energy and effective mass of the nuclear matter constituents, analyzing the density and momentum dependence.

All microscopic calculations based on bare nucleon-nucleon (NN) potentials which aim at a realistic description of nuclear matter should include three-body forces (TBF). In Ref. [1] within the self-consistent Green's functions formalism we computed macroscopic and microscopic properties of both symmetric and pure neutron matter starting from CD-Bonn [2] and Nijmegen [3] potentials implemented with the Urbana TBF [4]. Three-body forces have been included via an effective two-body interaction added to the NN potential in the in-medium T-matrix, derived by closing an outgoing nucleon line with an ingoing one in the three-body diagram in all topologically different ways. The calculation of the energy per particle at $T = 0$ in symmetric matter confirms the necessity of taking three-body forces into account in order to describe correctly the saturation behavior; the resulting neutron matter equation of state and the symmetry energy are in agreement with the current estimations.

We briefly discuss the effects of the inclusion of TBF on the single-particle properties. In particular we address the momentum and density dependence of the modifications of the spectral function $A(\mathbf{p}, \omega)$, the effective mass $m^\star(\mathbf{p})$, which is derived from

$$\frac{\partial \omega_p}{\partial p^2} = \frac{1}{2m^\star} \,, \qquad \text{where} \qquad \omega_p = \frac{p^2}{2m} + \mathrm{Re}\,\Sigma(\mathbf{p}, \omega_p) \,, \tag{1}$$

and the self-energy at the quasiparticle pole $\mathrm{Re}\,\Sigma(\mathbf{p}, \omega_p)$.

In Fig. 1 we present these modifications in the form of the ratio between the quantities computed with and without TBF, for isospin symmetric and pure neutron matter at zero temperature. The results are shown for the CD-Bonn potential, and are qualitatively similar when the Nijmegen interaction is used. For three different densities the ratios are displayed as a function of the momentum up to and above the Fermi momentum k_F. Overall we observe changes of about 20-30 %, the largest at higher densities as expected from the density dependence of the three-body potential.

The spectral function is broadened at all densities in symmetric matter, while the opposite effect is present in pure neutron matter, with a narrowing of the peak. The height of the peak can be

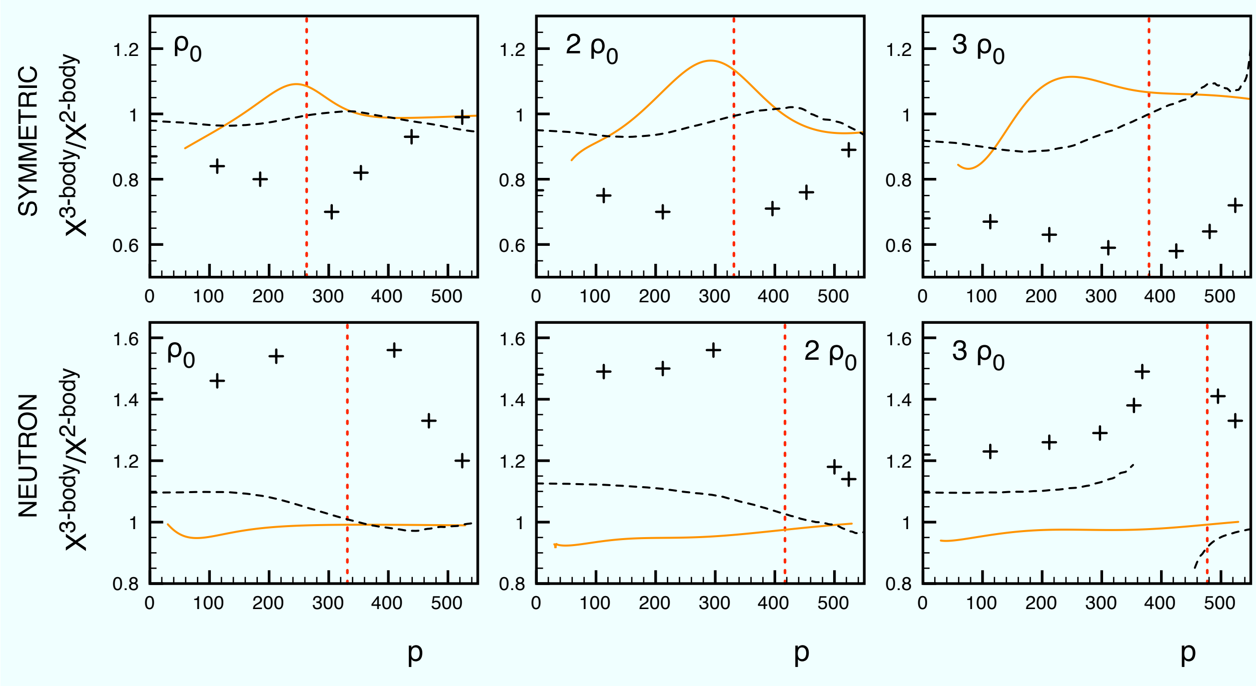

Figure 1: (Color online) Ratios (with vs. without TBF) of single-particle quantities as a function of the momentum. X stands for the real self-energy at the quasi-particle pole $\mathrm{Re}\,\Sigma(\mathbf{p},\omega_p)$ (dashed line), the effective mass $m^\star(\mathbf{p})$ (continuous line) and the value of the peak of the spectral function $A(\mathbf{p},\omega_{\text{peak}})$ (crosses). The upper (lower) panels refer to symmetric (pure neutron) matter at densities, from left to right, $\rho_0 = 0.16\,\mathrm{fm}^{-3}$, $2\,\rho_0$ and $3\,\rho_0$. The vertical dashed line indicates the Fermi momentum.

considered in order to study the momentum dependence of these effects. We notice that in both cases the modification gets stronger in the vicinity of the Fermi surface, signaling a change in the scattering behavior, and decreases in the high momenta region where $X^{3\text{-body}}/X^{2\text{-body}} \approx 1$.

The self-energy and the effective mass also show a different response depending on the isospin asymmetry. In general the real part of the self-energy is decreased (increased) by TBF and the effective mass at the Fermi surface is larger (smaller) when TBF are included in symmetric (neutron) matter. The largest modifications appear for intermediate momenta and are suppressed, in both cases, for $k > k_F$, with the ratios approaching the value of one.

The inclusion of three-body forces does modify the scattering behavior of nucleons in the dense medium. At low and intermediate momenta all single-particle observables are affected. Around k_F the single-particle spectrum undergoes the largest changes, then above the Fermi surface the effects in general are suppressed. These modifications can be reflected in the estimation of the in-medium nucleon-nucleon cross-section, relevant for heavy-ion reactions and the physics of neutron stars.

Acknowledgments Research supported in part by the Polish Ministry of Science and Higher Education, grant No. N202 1022 33.

References

[1] V. Somà and P. Bożek (2008), arXiv:0808.2929 [nucl-th].

[2] R. Machleidt, *Phys. Rev.* C 63 (2001) 024001

[3] V. G. Stoks, R. A. M. Klomp, C. P. F. Terheggen, and J. J. de Swart, *Phys. Rev.* C 49 (1994) 2950

[4] J. Carlson, V. Pandharipande, and R. Wiringa, *Nucl. Phys.* A 401 (1983) 59